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A MORE SIMPLIFIED VENTURI TUBE

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HYDRAULICS DIVISION

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A MORE SIMPLIFIED VENTURI TUBE

J. C. Stevens,[1] M. ASCE

INTRODUCTION

Wherever there is flow through a constriction in a pipe under pressure the drop in pressure, as the fluid passes this constricture, becomes an index of the rate of flow. This principle was expounded over a hundred and fifty years ago by Giovanni Battista Venturi, 1746-1822, a noted Italian engineer and scientist. The first practical application of this principle was made by Dr. Clemens Herschel[2] who developed, named and patented the Venturi tube as a practical device for measuring the flow of fluids in pipes.

Venturi tubes are now built by a number of manufacturers. Perhaps the best known among them today is Builders Providence of which its predecessor, Builders Iron Foundry, developed and marketed the Herschel Venturi Tube.

The standard Herschel tube follows closely the proportions set up by Dr. Herschel. In essence it includes a relatively short reducing inlet section with an included angle of about 20 degrees, a short accurately machined throat section, and an outlet section much longer than the inlet section and expanding to the size of the pipe line. Piezometer taps, generally manifolded, are made in the approach section and at the center of the throat section. The drop in the pressure head between the inlet and throat is an index of flow. The long tapered expanding section has a total angle of about 7 degrees in order to keep the total head loss at a minimum. However, shorter tubes are now offered by Builders Providence and others.

The flow recording mechanism generally makes use of mercury in the manometers to balance the pressures at the inlet and throat. Their tops are open to atmospheric pressure. In order to obtain measurable differential heads with mercury, the throat diameter is usually between 1/2 and 1/3 that of the inlet. The throat areas are thus 1/4 to 1/9 those of the pipe, and the throat velocities 4 and 9 times those of the pipe line of which the Venturi tube forms a part. In order to minimize the effects of cavitation in the throat section from such high velocities this portion is streamlined and machined with precision.

The writer became interested, some years ago, in simplifying the Venturi tube under the belief that many users would be quite willing to accept a trifle greater over-all loss of head, if necessary, in the interest of economy. If a Venturi tube is under a hundred feet of head what does it matter if the head loss is a foot more or less except perhaps in force mains from pumps? Accuracy is largely a matter of calibration and rougher and shorter tubes may be just as accurate as standard tubes.

There is an inherent source of error in the standard tube, in spite of precision machining, due to the change in direction of flow from converging

1. Cons. Hydr. Engr., Stevens and Thompson, Engrs., Portland, Ore.
2. Civil and Hydraulic Engineer, 1842-1930, Past President and Honorary Member ASCE.

velocities in the reducer to parallel flow in the throat section, and this effect is the more pronounced the higher the velocity tending to form a sort of vena contracta at the throat piezometer.

The writer's first attempt at simplification of the Venturi tube has been already described by him.[3] A further simplification is presented herein.

A Venturi Tube of Standard Reducers

In order to determine the efficacy of a tube made up of two AWWA cast iron reducers arrangements were made with the hydraulic laboratory of Oregon State College to conduct experiments on such a tube.

Figure 1 shows a tube made of an AWWA 12 x 8-inch reducer, a similar diffusor and the position of the piezometer rings in the inlet reducer. Figure 2 shows the tube under test in the laboratory. The piezometer taps were made by drilling holes through the wall of the reducer and threading them for 1/4 inch nipples which did not pass entirely through the wall. Four taps at the ends of right angle diameters were made at each piezometer ring. The taps in each ring were staggered about 2 inches circumferentially in order to avoid interference by the taps upstream.

The taps in each ring were manifolded by a ring of 1/4 inch copper tubing with a stop cock in each tap nipple and also in the pipes leading from the manifolds to the manometers.

As shown in Figure 1 the piezometer taps are numbered according to their distances in inches from the inlet face of the flange of the reducer.

In Series A tests piezometer rings were used in which the taps were drilled perpendicular to the axis of the pipe. The small ends of the reducer flanges were bolted together with merely a gasket between. Flows were obtained by weighing.

In Series B an 8 inch rising stem flanged gate valve was interposed between the small ends of the reducers with gaskets between flanges. In Series BF the valve was fully open, in Series B-3/4 it was 3/4 open, etc. Partial gate openings were proportionate parts of hand wheel revolutions for full gate opening.

In effect, therefore, 16 Venturi tubes with one reducer and one diffuser were available for testing by combinations with ring No. 3 and Nos. 9-13-17-19-21 and 23; also rings 5 and 7 each with Nos. 13-17-19-21-23 making 16 in all.

The over-all loss was indexed by rings 3 and 49. Only a few of the results can be given here.

Figure 3 shows the trend of the discharge coefficients vs. flow. These coefficients are independent of the discharge as they should be. It will be noticed that the shorter the distance between piezometer rings the higher the coefficient. Figure 4 brings out this fact more clearly wherein the coefficients are plotted against the distances between the piezometer rings. In Series A, also in Series BF with the valve open, the trends are similar; likewise in Series B-1/2 and B-1/4. The effect of the valve on the discharge coefficient either open or nearly closed is unimportant.

At first it was thought there might be an upward component of the velocity head in the piezometer tap. In Series A and B the taps were drilled perpendicular to axis of the reducer. Taps 9 and 13 were then drilled perpendicular to the wall of the reducer but no difference could be detected. The conclusion

3. Engineering News-Record, April 29, 1948, p. 112.

was reached that the converging stream lines in the reducer are practically parallel to the wall of the reducer and that the reason for the increase in the coefficient to practically 1.00 in all cases was due to the lesser friction the shorter the distance between piezometer rings. The differential head is due to the drop in velocity head plus the friction loss between the rings. When the friction loss becomes negligible the drop in pressure is due to the difference in velocity heads solely for which the discharge coefficient should be unity.

Friction losses were computed by the Manning formula with n = .015. The loss between each pair of rings 3 to 5, 5 to 7, 7 to 9, etc., was computed by first multiplying the average friction slope between each adjacent pair by the distance between them obtaining the friction head between each pair. These partial losses were then added to obtain the lost head between rings 3 to 9, 3 to 17, 3 to 23, etc. To these were then added the velocity head differentials between the same taps—designated as Δh. A close agreement with the observed Δh vs. flow was obtained as will be seen from Figure 5.

There was no ring Number 13 and Number 9 was not drilled until the experiments were half over. Therefore the coefficients for rings 3 to 9 and 3 to 13 are marked calculated in Figure 3. All other data shown were from laboratory observations.

In order to keep total losses in the diffuser to a minimum requires a nice balance between its length and rate of expansion. Dr. Herschel found that a diffuser with a total included angle of about 7 degrees gave the minimum loss from friction and eddies combined.

In the Simplified tube the over-all losses can be materially decreased over those shown in Table 1 by using two diffusers, for example, an 8 x 10-inch and a 10 x 12-inch in tandem. Except in special cases, however, such refinement is not necessary.

Water Manometers Used

With the Simplified Tube the pipe pressures are not balanced by mercury but by water under sufficient air pressure to balance the pipe pressures. The tops of the glass manometer tubes have gage glass fittings and are connected by a small tube into which air can be pumped. Thus, the water in the manometer tubes may be under not only one atmosphere but under several. This does not affect the differential head in the slightest.

A differential of a foot of water can be read with the same degree of accuracy as a foot of mercury but to produce a differential of a foot of mercury requires 13.56 times as much pressure drop between inlet and throat of a Venturi tube as for a foot of water. Thus, where water manometers are used throat velocities can be materially reduced without any sacrifice of accuracy and with the decided advantage of eliminating cavitation effects.

For all practical purposes a 12-inch water differential is sufficient for the maximum flow through the tube. By placing the inlet piezometer ring near the flange of the reducer any desired water differential can readily be secured by positioning the throat ring in the net reducer length where the diameter is found that will give the throat area to produce the required differential. The mean diameters of both the inlet and throat rings should be carefully calipered after taps have been drilled and the flow formula made to fit them.

For any tube the flow through it is given by

$Q = K\sqrt{ah}$ in cfs

where $K = \frac{8 a_2 C}{\sqrt{1 - X^2}}$, X = ratio of areas[4]

a_2 = the throat area in sq. ft., and C = the discharge coefficient

Table 1 gives the essential dimensions for standard AWWA reducers. Each end of the reducer has a short length the same diameter as the pipe diameters to which it is joined regardless of class; this determines the net reducer length.

Table 1. Standard AWWA Reducer

Reducer sizes All Classes	Length-face to face of flanges	Net length of reducer
All 12" pipes and smaller	26 inches	18 inches
All 14, 16, and 18-inch pipes	28	20
All 20 and 24-inch pipes	34	26
30 X 18-inch reducers	33.5	26
30 X 20 to 36 X 24-inch reducers	73.5	66
36 X 30 to 42 X 24-inch reducers	73.0	66
42 X 30 to 48 X 36-inch reducers	72.5	66
48 X 42-inch reducers	72.0	66

Venturi Tubes Compared

In order to show the difference between the Herschel tube and the Simplified tube described herein Table 2 was prepared. It shows throat velocities, differential heads and over-all lost heads with various tubes in a 12 inch cast iron pipe. It has been common to tabulate over-all losses in per cent of the differential head and is usually given in inches of water when pressures are balanced by mercury. Where water manometers are used under air pressure however, and differentials are low, it is better to express over-all loss in terms of that in an equivalent length of the pipe of which the tube forms a part.

It appears from Table 2 that the total lost head in terms of an equivalent length of 12 inch cast iron pipe for the Simplified tube should be approximately the same as that for a Herschel tube with a throat diameter of 5.7 inches.

The greater part of the lost head in either type of a tube is due to eddies in the diffuser. The longer the diffuser the less the eddy loss but the greater the friction.

The simplified Venturi tube may be made of a variety of materials including cast iron either flanged or bell and spigot, welded steel and concrete—either formed or made of standard fittings. Where tuberculation is likely to be troublesome cast iron or steel pipe and fittings may be had with cement lining.

4. Venturi Tubes are not always round hence the use of the ratio of areas.

Table 2. Venturi Tube Characteristics Compared

		(1)Herschel Tubes			Simplified Tubes		
Piezometer rings					3-9	3-17	3-23
Throat diameters-inches		4.00	5.00	6.00	10.92	9.03	8.12
Length-feet		11.0	9.9	8.8	4.4	4.4	4.4
	Throat Velocities - Feet Per Second						
Flow	1 cfs	11.5	7.35	5.10	1.54	2.24	2.78
	2	23.0	14.7	10.2	3.08	4.50	5.53
	3	34.5	22.0	15.3	4.62	6.74	8.34
	4	-	29.4	20.4	6.15	9.00	11.1
	5	-	36.8	25.5	7.70	11.2	13.9
	6	-	-	30.6	9.24	13.5	16.7
	Differential Heads - Feet of Water						
Flow	1 cfs	2.08	0.83	0.39	.014	.057	.103
	2	7.80	1.82	1.52	.054	.227	.405
	3	18.7	7.70	3.54	.118	.505	.915
	4	-	13.3	6.40	.211	.909	1.52
	5	-	21.6	10.2	.348	1.42	2.56
	6	-	-	13.8	.480	2.06	3.63
	Ratio of Lost Head In Tube to That in Same Length of 12" CI Pipe						
Flow	1 cfs	26.8	9.6	4.8	6.2		
	2	26.5	8.7	4.6	6.1		
	3	29.5	8.9	4.3	6.0		
	4	-	9.8	4.8	6.1		
	5	-	10.1	4.9	6.2		
	6	-	-	4.2	5.4		
Average		27.6	9.4	4.6	6.0		

(1) Selection of Main Line Meters—J. C. Thoresen, Water Works & Sewerage, June, 1953.

A Flow Recorder for Venturi Tubes

The writer has developed a flow recorder that utilizes water manometers wherein the differential head is obtained by a photocell rider surrounding each small glass manometer. The indices of the riders follow the water level in the manometers. A graph is produced of the rate of flow and the volume may be totalized.

Where sewage is to be metered the recorder controls include facilities for automatically back flushing with clear water the pipes leading from the Venturi tube manifolds to the manometers at appropriate time intervals.

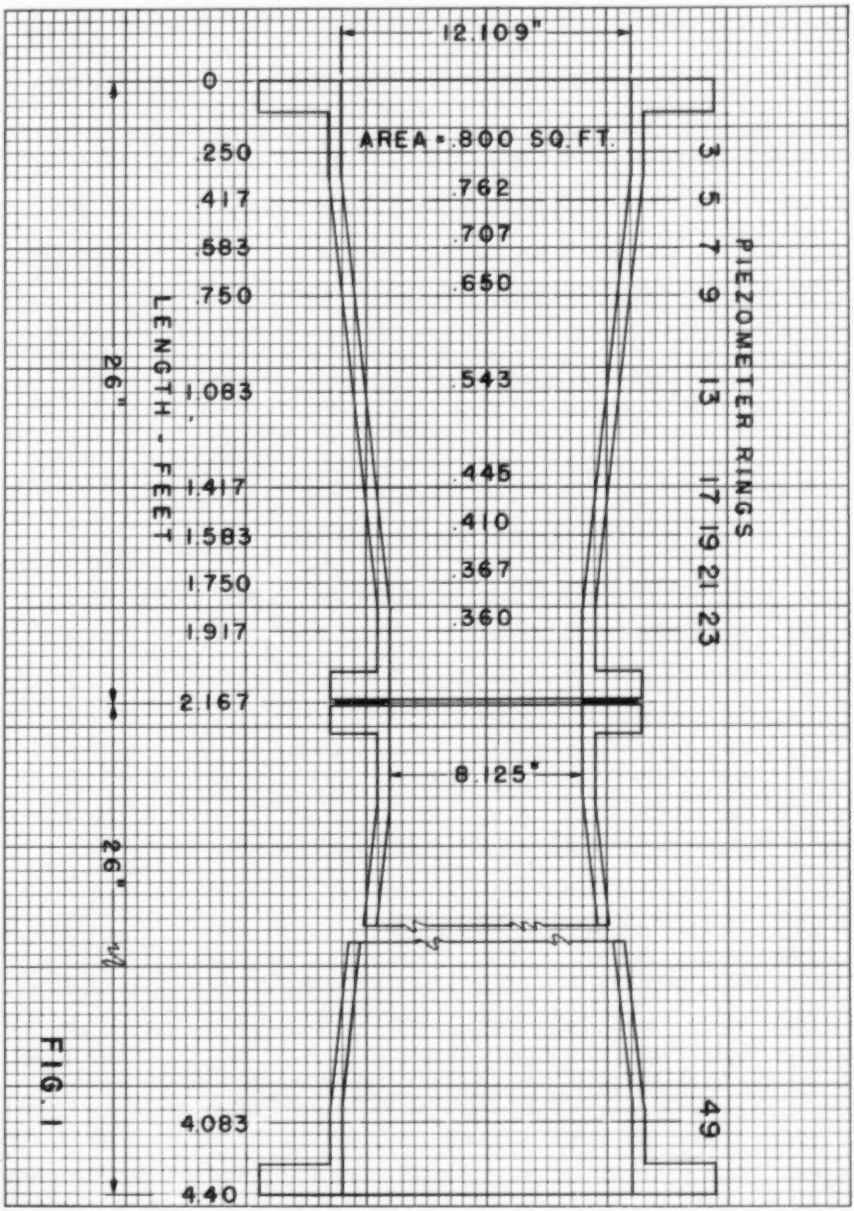
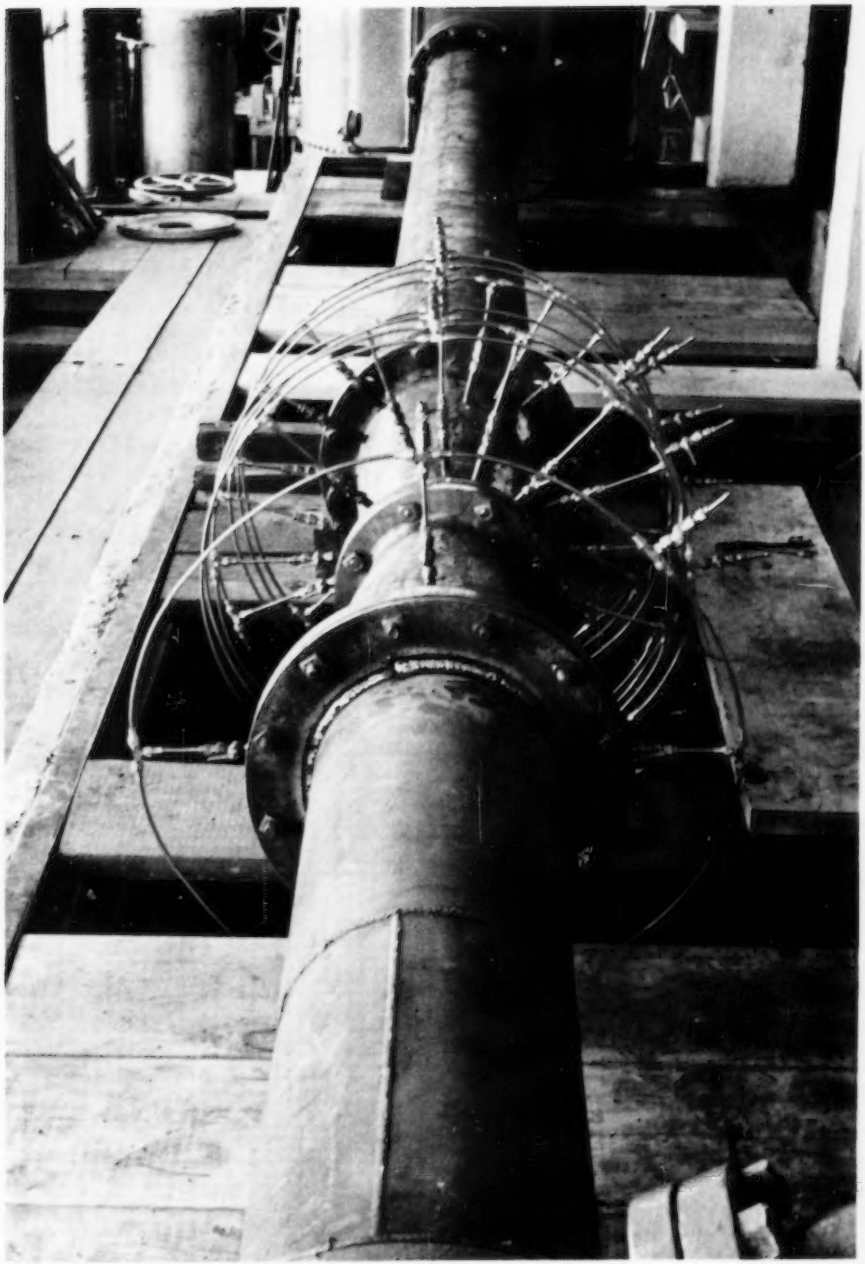

12.109"
AREA = 800 SQ. FT.
0
250
417
583
750
1.083
1.417
1.583
1.750
1.917
2.167
4.083
4.440
26"
26"
LENGTH - FEET
.762
.707
.650
.543
.445
.410
.367
.360
8.125"
3 5 7 9 13 17 19 21 23
49
PIEZOMETER RINGS

FIG. 1



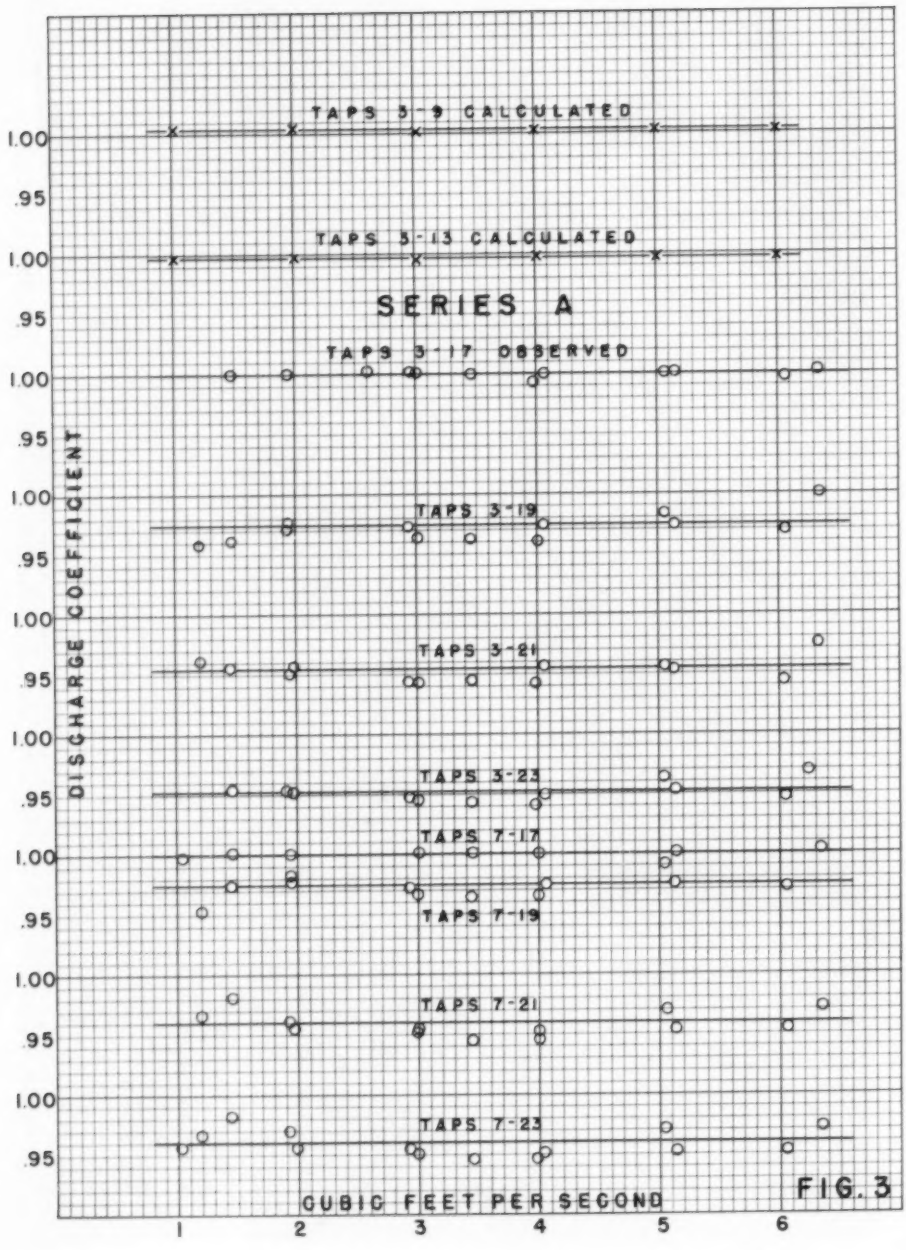

TAPS 3-9 CALCULATED
TAPS 3-13 CALCULATED
SERIES A
TAPS 3-17 OBSERVED
TAPS 3-19
TAPS 3-21
TAPS 3-23
TAPS 7-17
TAPS 7-19
TAPS 7-21
TAPS 7-23
DISCHARGE COEFFICIENT
1.00
.95
CUBIC FEET PER SECOND
1
2
3
4
5
6

FIG. 3

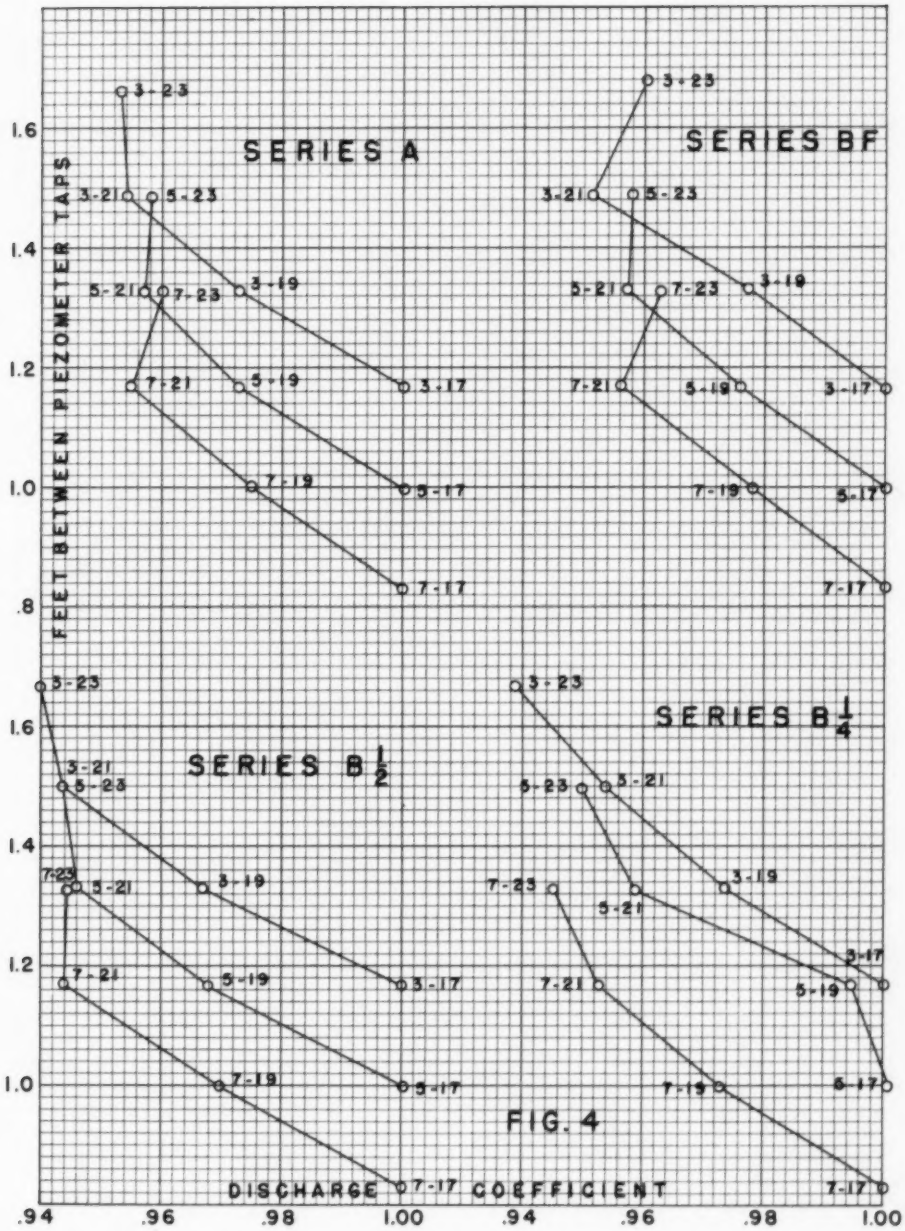

SERIES A
SERIES BF
SERIES B 1/2
SERIES B 1/4
FEET BETWEEN PIEZOMETER TAPS
DISCHARGE COEFFICIENT
1.6
1.4
1.2
1.0
.8
.94
.96
.98
1.00
3-23
3-21
5-23
5-21
7-23
3-19
7-21
5-19
3-17
7-19
5-17
7-17

FIG. 4

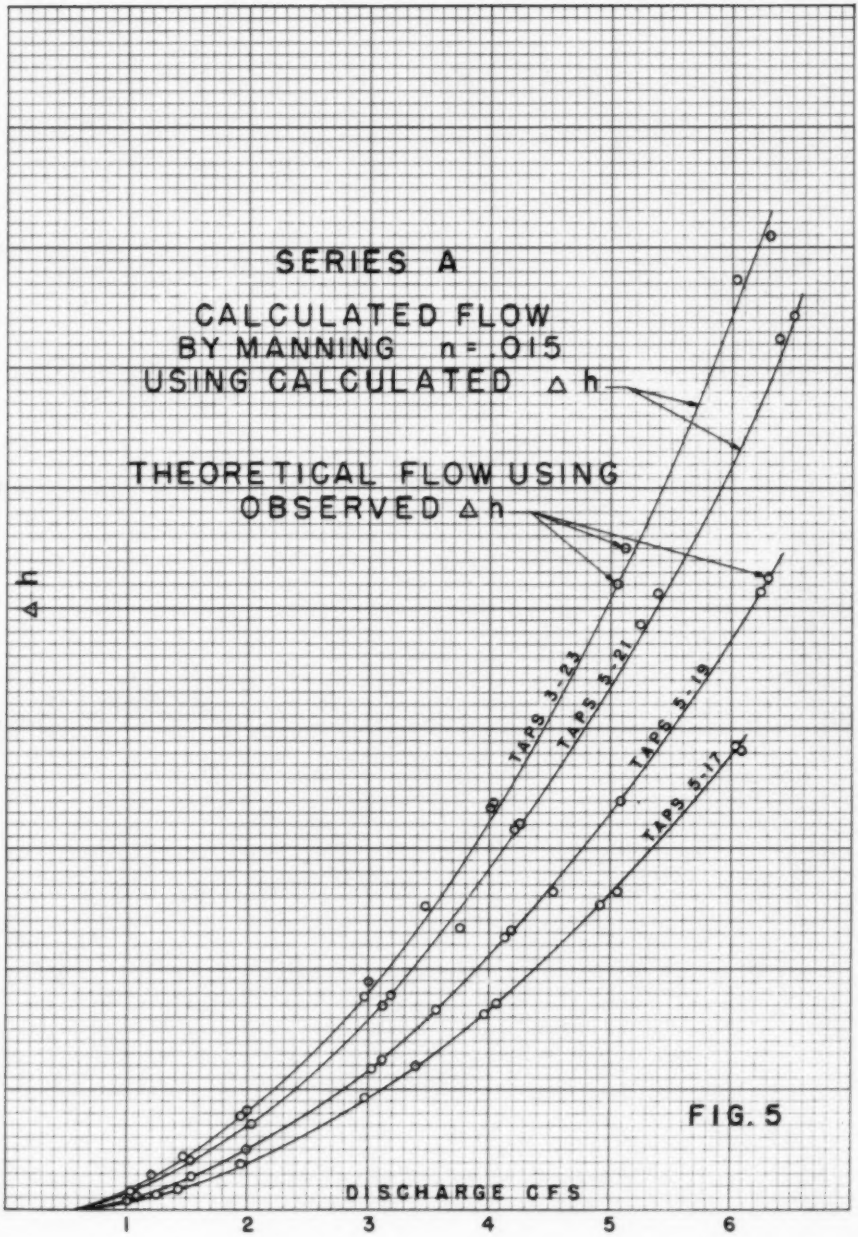

SERIES A
CALCULATED FLOW
BY MANNING n = .015
USING CALCULATED Δ h
THEORETICAL FLOW USING
OBSERVED Δ h
Δ h
DISCHARGE CFS
TAPS 3-23
TAPS 5-21
TAPS 5-19
TAPS 5-17
1
2
3
4
5
6

FIG. 5